About The Project Physics Course

An Introduction to the Teacher Resource Book

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An Introduction to the
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THE PROJECT PHYSICS COURSE IN BRIEF

FOR USE OF TEACHERS AND OTHERS WHO NEED A SHORT STATEMENT ABOUT THE PROJECT PHYSICS COURSE

This is an introductory, one-year physics program for high school students that presents a core of coherent ideas in an integrated learning sequence, using a multimedia system for a multilevel, flexible course. This course is based on Harvard Project Physics, a national curriculum improvement project, which was funded by the U.S. Office of Education, the National Science Foundation, the Carnegie Corporation of New York, the Alfred P. Sloan Foundation, The Ford Foundation, and Harvard University.

The Project Physics Course selects from the enormous bulk of possible materials a sequence of coherent ideas that deals with good physics and can be related to a clear story line. Besides "pure physics," the course shows how physics connects with other sciences, particularly astronomy and chemistry, and includes aspects of the philosophy and history of science that put the development of the major ideas of physics into a humanistic and social context.

The Project Physics Course provides a basic text for the course that is shorter than almost any other physics program. Certain topics found to be difficult to learn merely by reading are dealt with through other components of the program. The variety of learning aids for the Project Physics Course are assembled in an integrated, multimedia system, including text, readers, film loops, films, experiments with specially coordinated laboratory apparatus, programmed instruction booklets, transparencies, student handbook, and teacher resource book.

The structure of the course allows students and teachers to select and emphasize aspects which interest them most. Those classes (or individual students) who can complete the core content in less than the school year are given ample opportunity to explore further or more deeply through selection of additional topics and learning aids. These include additional text units, other experiments and activities, additional films and film loops, other sections of the readers, and individual projects. Different students, from the science-shy to the science majors, may demonstrate achievement in different ways, whether it lies in pursuing a more mathematical treatment, doing further laboratory experiments, or historical readings. The most crucial element in any physics course is the teacher, who determines the final shape of the course. The teacher of this course may choose from a wide range of styles the one most congenial to him. Some teachers who like to deemphasize their role as lecturers and transmitters of information prefer seeing themselves as counselors, guides, and amplifiers of latent enthusiasm; their style of teaching allows students to show different rates of progress through different aspects of the course.

The view shared by most of the nation's thoughtful scientists, educators, policy makers, and physics teachers is that a physics course with a cultural component is needed by nearly everyone. Nobel Prize physicist I. I. Rabi—a member of the Advisory Committee of the Project—spoke for this view when he said that physics now lies at the "core of the humanistic education of our time," and he added, "Science should be taught at whatever level, from the lowest to the highest, in the humanistic way. By which I mean it should be taught with a certain historical understanding, in the sense of the biography, the nature of the people who made this construction, the triumphs, the trials, the tribulations." The Project Physics Course follows the precept that a good introductory course today can validly use the history and social consequences of science as teaching aids on various occasions without causing physics to yield its just claim as an individual discipline of primary importance.

Every component of the Project Physics Course was tested in hundreds of classrooms throughout the United States and redesigned on the basis of these tests. Through anonymous questionnaires, the overwhelming majority of students reported that they would recommend the course to their friends. Besides enjoying it, students profited intellectually as shown on achievement tests. It is encouraging that even students who are regarded as having modest academic talent show gains in achievement scores as great as those of the regular physics student.

INTRODUCTION TO THE PROJECT PHYSICS COURSE

GENERAL BACKGROUND

The Project Physics Course is based on the ideas and research results of the Harvard Project Physics curriculum development group. This national course improvement effort formally began in the spring of 1964. At that time Gerald Holton, James Rutherford, and Fletcher Watson of Harvard University received support from the United States Office of Education and the National Science Foundation, which enabled them to bring together professional people from all parts of the nation to work on the improvement of physics education.

Informally, the Project had started several years earlier. In 1962, when Rutherford was a physics teacher and science department head in a public high school, Holton and Watson agreed to collaborate with him in testing the feasibility of designing a new physics course. With the story-line and aims in Gerald Holton's college text, *Introduction to Concepts and Theories in Physical Science*, as a general guide, preparation of a course outline and instructional materials was begun. In 1962 the group of founders obtained initial support from the Carnegie Corporation in New York, which allowed them to test their materials. The success of these tests, coupled with the increasing national awareness that something needed to be done about decreasing high school physics enrollments, led to the formation of Harvard Project Physics. The decision to expand to a national program was stimulated by a request from the National Science Foundation late in 1963.

The general purposes of Project Physics remained constant from the beginning, when three individuals worked without support, through the time of peak developmental activity involving hundreds of scientists, teachers, psychologists, artists, and other professional participants from throughout the United States and Canada, as well as thousands of students in trial classes. To some degree, the purposes reflected the fact that the co-directors of the Project were, respectively, a university physicist, a professor of science education, and an experienced high-school physics teacher.

The chief purposes were:

1. *To design a humanistically oriented physics course.* Harvard Project Physics would show the science of physics in its proper light as a broadly based intellectual activity that has firm historical roots and that profoundly influences our whole culture.

2. *To develop a course that would attract a large number of high school students to the study of introductory physics.* Such a course must be meaningful not only to those who are already intent on a scientific career, but also to those who may not go on to college and to those who while in college will concentrate on the humanities or social sciences.

3. *To contribute to the knowledge of the factors that influence science learning.* In addition to its long-term value, this extensive educational research should supply information needed by teachers and administrators in deciding whether to introduce the course and, if so, in what way and for which students. The research results have been reported in professional journals and dissertations (see Bibliography), and in the book *A Case Study in Curriculum Evaluation: Harvard Project Physics.*

Assumptions About Physics and its Presentation

The first two Harvard Project Physics goals—developing a humanistically oriented course and increasing enrollments in high-school physics—were based on certain assumptions about the nature of physics, the needs and preferences of students, the role of teachers, and the place of introductory physics in high school education. It may be helpful to state some of these assumptions explicitly.

1.Physics, as usually taught and presented in texts, provides a description and explanation of the main parts of the physical universe, as well as a way of thinking about the universe. The conceptual content of physics is of surprisingly small extent, since it is composed of a limited set of related principles. This content is not immutable; parts of it change by growth and restructuring, and occasionally it undergoes a radical modification. Understanding this content and the way it grows is far more important than memorizing any number of superficial facts and isolated laws and equations about the physical world.

2.The content of physics as it exists at any given time is a powerful tool for scientists and for society in general. The scientist uses it to understand nature, and other professionals, for

example, engineers, technicians and businessmen, use it to help them gain control over aspects of the environment. Thus, physics has practical social consequences that cannot be left unexamined.

3. Physics is something more than collective, published achievement. For a large group of professionals it is also a day-to-day activity; a style of living, thinking and acting. Since the days of Galileo, physics has been a lively affair, often characterized by dramatic personal involvement. The questions asked, the kinds of answers sought, the theoretical and experimental techniques employed, the instruments relied upon and the relationships between physicists —all these make up physics and vary from place to place and from time to time. Scientific inquiry is too dynamic and too multifaceted to be portrayed by any simple delineation of steps, procedures, or method.

4. While physics has acquired its own identity as a field of scientific inquiry, it is not intellectually and operationally isolated from other sciences. In fact, in both content and methods it overlaps other sciences. In any actual problem worked on by a physicist, the lines between physics, chemistry, mathematics, metallurgy, and other technologies, for example, may be drawn only in a rather arbitrary way.

5. The activity of doing physics is related in many ways to man's intellectual and aesthetic activities outside the realm of the natural sciences. Specific case studies show that the development of physics has been and continues to be influenced directly by economic, social, political, philosophical, and religious conditions and beliefs. These, in turn, are affected by developments in physics and in other sciences.

Assumptions About Students

1. Regardless of their vocational goals, most students at the senior high school level will benefit from knowing some physics. Physics should not, as it has too often been in the past, be reserved for the small fraction of high school students who have the most highly developed academic skills and who are already interested in physics or engineering. A student will enrich his life by studying physics even if he never reaches a sophisticated understanding of any portion of the subject. Just as in history, music and other fields, some understanding of physics is far better than none. Indeed, there is an essential minimum knowledge of physics without which a person can hardly be considered educated, for he would be ignorant of the very world in which he must live and act. After the Harvard Project Physics course has been taught in a school for one year, there has usually been a significant rise in enrollment in the following years. Experience so far indicates that, depending upon the status of physics in the school initially, teachers can expect physics enrollments to increase anywhere from 20% to 40% each year until the proportion of graduates who have taken a course in physics reaches half or more.

2. Most students can learn a substantial amount of physics. Not all students will reach the same degree of comprehension but nearly all can gain at least a qualitative understanding of the major ideas. This is especially true when physics is thought of in the broad context outlined above.

3. Different students will be interested in different aspects of physics. The theoretical and mathematical treatment of physics found in most courses appeals to some students. Some students find historical and biographical considerations equally or even more interesting; others enjoy the philosophical issues raised; while still others excel in experimentation or are most interested in technological applications. Each of these interests is a valid avenue to an understanding of physics. There is no single "right" way, and each way should be rewarded if pursued seriously and successfully. Encouraging different interests is one way to make possible the experience of success for each student in the classroom.

4. Different students have different learning styles, skills, and capabilities. Learning rates vary from student to student, as do responses to various learning media and to different teaching techniques. The skillful teacher does not ignore these individual learning differences. On the contrary, he will take these factors into account as he tries to guide each student.

Assumptions About High School Physics Teachers

1. Teachers of physics differ one from another in many ways: in physics training; in social or economic backgrounds; in knowledge of astronomy and other sciences, in knowledge of the history and philosophy of science and of the humanities; in acquisition of laboratory, mathematical, and speech skills; in point of view about the place of physics in education; in understanding of and rapport with teenagers; in personality, and in drive. These differences are not to be deplored but rather to be accommodated. A course should be flexible enough to take into account this large diversity of teacher characteristics, making it possible for each teacher to shape the course according to his own strengths.

2. The classroom teacher is, and ought to remain, the primary decision maker in his domain. The content, emphasis, level of difficulty, organization of instruction, and other essential features of a course in physics must be determined by the physics teacher. No matter how carefully prepared the instructional materials are, a course must finally be shaped by the teacher. There are no "teacher proof" courses.

3. A teacher can increase a student's motivation and help him to learn more effectively, but the teacher cannot do the work of learning for the student. It is now widely agreed that, with suitable guidance from the teacher, students should gradually be allowed to be more independent. This can involve learning from other students, individualized instruction, and other techniques. In each case there is little emphasis on the teacher's role as dispenser of information to a whole class at one time, and increased emphasis on a role that motivates students to undertake meaningful independent study. The teacher guides them through the learning materials, and provides help to individual students when they need it.

Assumptions About the Place of Physics in Education

1. Introductory physics, like introductory history, art, music, literature, and language, should first of all contribute to liberal education. It should serve the student by enhancing his appreciation of the world around him. This does not necessarily exclude, of course, the equally important aim of helping a student to discover his talent in a physical science.

2. An introductory physics course should not assume that all students are heading towards scientific careers. However, a successful science course will certainly identify and nurture those who wish such careers, motivate some students in this direction, and inform all students of the nature of work in science professions and in occupations related to science.

3. One can never learn enough in any introductory course to serve a lifetime. A physics course will have done much if it instills in students a desire for learning science throughout their lives, and assists them in developing the necessary learning skills. At the very least the course should avoid a common complaint about physics courses in the past, namely that they induce a flight from all future contacts with science!

SPECIFIC GOALS OF THE PROJECT PHYSICS COURSE

In view of these assumptions about students, teachers, and the educational purposes of introductory physics, the first two general aims of Harvard Project Physics—to develop a humanistically oriented physics course, and to help increase high school physics enrollments—can be restated in somewhat more specific terms. The Project Physics Course and course materials were designed to accomplish the following goals:

1. To help students to increase their knowledge of the physical world by concentrating on the ideas that characterize physics as a science at its best (for example, the conservation laws), rather than concentrating on isolated bits of information (such as the lens formula).

2. To help students see physics as the many-sided human activity that it really is. This means presenting the subject in historical and cultural perspective, and showing that the ideas of physics have not only a tradition but methods of adaptation and change.

3. To increase the opportunity for each student to have immediate rewarding experiences in science while gaining knowledge and skill that will be useful throughout life.

4. To make it possible for teachers to adapt the physics course to the wide range of interests and abilities among their students.

5. To recognize the importance of the teacher in the educational process, and the vast spectrum of teaching situations that prevail.

EVALUATING THE PROJECT PHYSICS COURSE

How nearly does the Project Physics Course achieve the goals listed above? There are two quite different ways to go about finding an answer to this question. One is by inspection of the various materials comprising the course, and of the statements and suggestions in the *Teacher Resource Book*. Each teacher should look with some care at the course materials and then answer for himself pertinent questions. Do the materials present physics in the broad cultural context suggested? Does the course include most of the physics topics he believes he would like to teach? Is there enough variety for most of his students to find something of interest? Do the books, readers, laboratory and out-of-school activities, film loops, transparencies, and all the rest provide the flexibility necessary to adapt the course to individual differences? Would he, given his own situation and characteristics, be able to teach this course effectively?

In order to answer such questions honestly, the teacher must have the opportunity to study the materials in detail. This is one reason why preparation in a methods course summer institute, an academic year institute, or in-service institute largely or fully dedicated to the Project Physics Course is so valuable. Most teachers who have attended such institutes, and thus have had the chance to study the materials carefully, have reported that in their judgment the instructional materials do make it possible for them to attain such goals.

The second approach to judging the Project Physics Course is the record of experience. Studying materials in abstraction from actual classroom teaching can never be entirely satisfactory. At best it may indicate what is possible; but one can never know whether the possible will be attained until the test of experience has been made.

This experience may be that of the individual teacher, or it may be collective. Harvard Project Physics itself has attempted to find out what results were obtained when the course was taught to different students with different teachers under different circumstances in many different parts of the country. The study was unique among curriculum development studies in terms of its large scale and its rigorous research design, just as the Project itself was unique in the number of detailed revision cycles based on teacher feedback. The results are fully reported in a publication entitled, *A Case Study in Curriculum Evaluation: Harvard Project Physics*. We believe it is fair to say that these results, which explain some of our own satisfaction with the course, merit your careful consideration. A very brief summary of the Project research and evaluation activities follows.

SOME EVALUATION FINDINGS

The development of Harvard Project Physics was accompanied by a massive evaluation undertaking. Three brief summaries of evaluation findings are included here. The condensations omit many subtleties of research methods, instruments, and statistics which can be found in the complete report of the evaluation, *A Case Study in Curriculum Evaluation: Harvard Project Physics*.

Research design Part of the research design involved the selection of fifty-three teachers at random from an NSTA list of over 16,000 high school physics teachers in the continental United States during the school year 1968–1969. Thirty-four teachers were assigned to attend a summer institute and then to teach Project Physics. The remaining nineteen teachers were requested to continue teaching what they had been teaching. Because the Harvard Project Physics and control groups were randomly assigned from the randomly selected pool, the differences found between the groups can be legitimately generalized to the national population of high school physics teachers. Note that almost all, if not all, previous research on curriculum has used volunteer groups and has not legitimately allowed such statistical generalizations.

Students' course satisfaction At the end of the course, the student averages on a measure of satisfaction were significantly higher for classes taught by Harvard Project Physics teachers than for control teachers. In fact, this finding was the most significant statistically in all the research. The satisfaction score was a composite of questionnaire responses. The questionnaire items with the greatest differences showed Harvard Project Physics students more likely to agree with these statements:

> I think this physics course is designed in such a way that even those who have little background in mathematics can gain much from the course.
>
> The book was really enjoyable to read.
>
> I think learning about men and women who made physics grow helped to make the course more interesting.
>
> I hope they don't change the course too much.

Furthermore, Harvard Project Physics students were *less* likely to agree with the statements:

Physics is one of the most difficult courses I have taken in high school.

No matter how you look at it, physics had to be a difficult course.

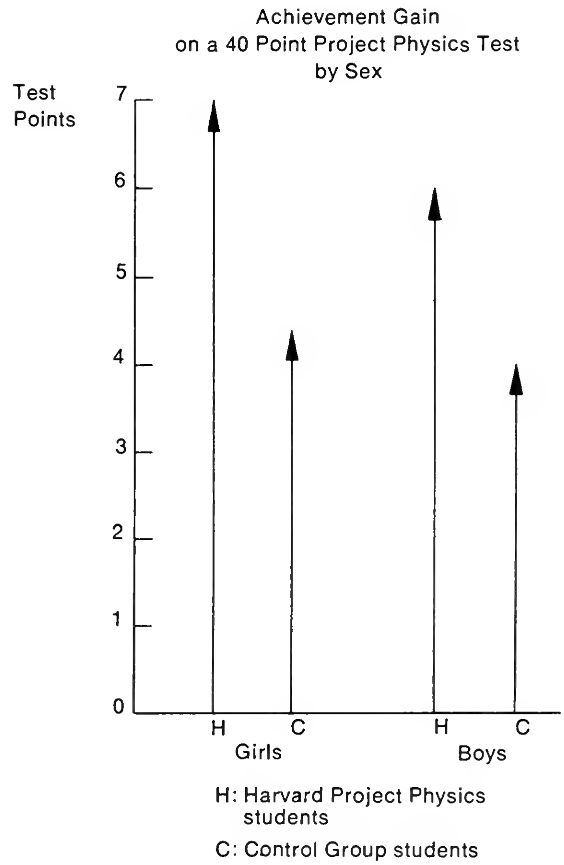
Because the satisfaction score is so closely tied to major goals of Harvard Project Physics, further analysis was done to see whether this advantage might be lost for certain kinds of students. Satisfaction averages were computed for students divided into three IQ levels, and then further subdivided by sex, by three levels of initial interest in physics, by three levels of an attitude score—("Theoretical Outlook,") and by three levels of a personality score—("Dogmatism.") The Project Physics Course presents science as more speculative and less absolutely true than most other courses. The Dogmatism scores were tried because it was thought that perhaps students who tended to be authoritarian and dogmatic might be uncomfortable with the lack of certainty.

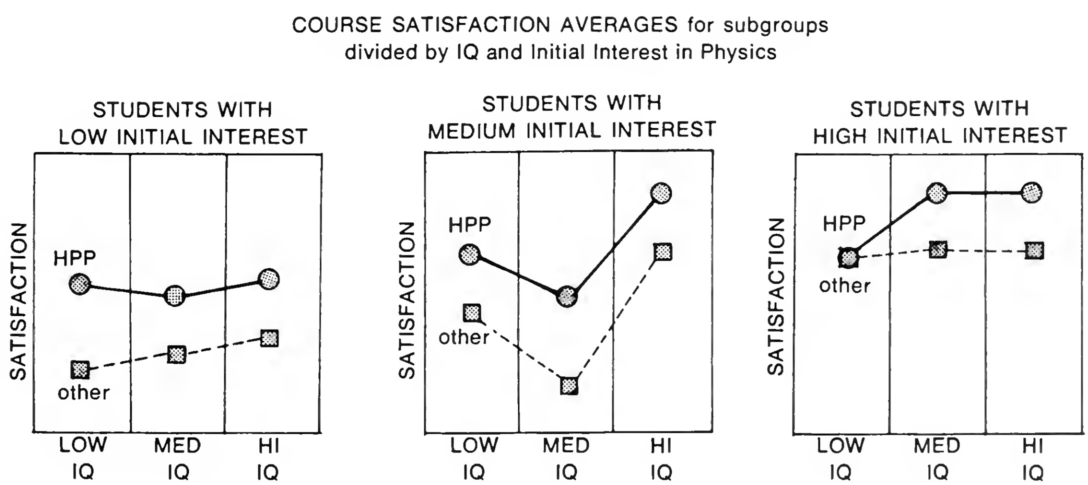
The results of these breakdowns of data are shown graphically below. Each plotted point represents 25 or more students.

As inspection of the graphs shows, the satisfaction advantage for Harvard Project Physics is rather uniform across all the subdivisions. If the advantage is less in any case, it is for low-IQ students with high initial interest or a strong theoretical outlook. Remember that all of these students elected to take physics. Even the "low-IQ" group had an average IQ of about 106.

Student sex differences The achievement gain was greater for girls than for boys on the Harvard Project Physics achievement examinations. This was a gratifying result for it suggests that this new curriculum appeals to a greater number of students who have diverse interests.

In addition to achievement, male and female physics students were contrasted on attitudinal





and personality measures. From all the measures studied, four distinguishing patterns were identified. Girls were higher on verbal aptitude, had great social values, were more cautious about science experiences and emphasized aesthetic values over theoretical values. These findings are not surprising but are probably worth remembering.

Students who normally would not take physics About forty teachers were asked to invite a number of students who had not chosen to take physics to try the new course. In most instances, teachers explained Harvard Project Physics to students and asked them to reconsider their decision. In other schools the guidance counselors made the selections. A total of 194 students accepted. The recruited group of students was distinctly less "academic" than the regulars. They had significantly lower scores on academic activities, on physics achievement pretest, on interest in physics, and on IQ. The average IQ for regular physics students was 116; for recruits, 108. Although the recruits began lower and ended lower on almost all tests, they showed greater *gains* than the regular students on all but a "tinkering" activities score. However, on only one score, "Lab-fun," was the greater gain for recruits statistically significant.

While the collective experience of teachers and students as reported in the evaluation study may buttress a teacher's own impressions gained by studying the materials himself, it is the teacher's own experience that is the most important. This suggests that during the first year a teacher ought to teach the course more or less as outlined in this *Teacher Resource Book*, keep careful notes of his observations of the results, and aim at least to cover the material in the six basic units. A teacher may wish then, during a second year, to modify the course in some ways (for example, by adding a supplemental unit or two), and to favor those teaching approaches which seemed to work best for him. This process of adaptation and modification based on daily classroom evaluation should continue until a teacher is satisfied that the course achieves the goals set for it. This doesn't imply that the course need ever be frozen. The richness of course material should encourage and enable teachers to respond to changing circumstances and to their own dynamic interests with a continually evolving course.

In the years ahead, the learning materials of the Project Physics Course will be changed as often as is necessary to remove remaining ambiguities, clarify instructions, and to continue to make the materials more interesting and relevant to students. We therefore urge all students and teachers who use this course to send to us (in care of Holt, Rinehart and Winston, Inc., 383 Madison Avenue, New York, New York 10017) any criticisms or suggestions they may have.

ABOUT ENROLLMENTS

One of the hopes of the staff of Harvard Project Physics was that the use of this course would help stem the tide running against the study of physics in high schools in the United States. The number of senior high-school students taking any variety of physics course was, according to the most recent statistics of the U.S. Office of Education, only 526,000. This is less than 20% of the total number of seniors in high schools. In the past two decades, the percentage of students taking high-school physics has been dropping while enrollments in biology, chemistry, and mathematics courses have generally either held their own or shown gains. In the 1950's, one student in four took physics; in the 60's, the fraction was down to less than one in five. Thus each year more than eighty percent of the U.S. high-school students are now graduating without having had a physics course in senior high school, although the subject remains basic regardless of later career plans. Nothing like this is experienced in other developed nations.

While it is too early to tell whether and when the introduction of the Project Physics Course can help improve this dismal record, early indications from recent studies are hopeful. One set of data comes from an independent study carried out at Knox College, Salesburg, Illinois among the "alumni" of its Harvard Project Physics teacher-training institute. Thirty-five participants from 35 schools responded to a request for information. Against an only slowly changing total twelfth-grade population in these schools over the last three years. It was found that the introduction of the Project Physics Course changed their physics enrollment statistics drastically. The school year 1967–8 was one year before Project Physics in an interim version was introduced in these schools, and the total physics enrollment in all types of courses was then 1683 students (of which 17% were girls). During 1968–69, the Harvard Project Physics was begun with a total of 298 students. By 1969–70, the total number of students enrolled in all three types of courses taught (the Harvard Project Physics, PSSC, and traditional physics) was 2456. This total figure included 823 students (32% of them girls) in Harvard Project Physics courses.

In short, the total physics enrollment in two years since 1967-68 had jumped by 773 students, or 41%.

And it should be noted that these schools made their gains not at the expense of significantly decreasing enrollments in other types of physics courses: during this same period the enrollment in traditional physics courses changed from 674 to 610 students, and in PSSC from 1009 to 1023. The 823 Harvard Project Physics Course students—one third of all the students taking physics in those schools in the year 1969–70—may well be considered *newly found students* who, through Harvard Project Physics, were brought to the study of the subject.

In a second study, a short questionaire was sent at the end of the 1969–70 school year to teachers who were using the Project materials in their interim versions. From all parts of the U.S., 222 replies containing at least some usable data were returned. The survey yielded the following results, which must be measured against the continuing percentage decreases in student enrollments in physics across the nation. The total number of 12th-grade students in these 222 schools was approximately constant at about 96,200 students over the period from 1968 to 1970. But the total enrollment in all types of physics courses from one year to the next changed from 18,160 (or 19%) in 1968–69 to 20,689 (or 21.6%) in 1969–70. The number of scheduled sections of all types of physics courses increased from 780 to 885. Again, the growth may be considered at least in good part to be coupled to the fact that during the same period, the number of Harvard Project Physics students in those schools increased from 5,805 to 11,475.

Finally, a third study of this type was made in which "alumni" of teacher-training institutes held at San Diego State College were asked about the growth of student enrollments in their Harvard Project Physics classes. There were replies from 51 participants in 51 schools, mostly in California and Western States. The number of Harvard Project Physics students went up as follows:

1967–68:	124
1968–69:	399
1969–70:	1231

These increases—by a factor of about 3 between the first and second year, and again between the second and third—are not untypical of the experience found in many schools that have introduced the course.

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Bar Yam, Miriam. *The Interaction of Student Characteristics with Instructional Strategies: A Study of Students' Performance and Attitude in a High School Innovative Course.* Unpublished doctor's thesis. Cambridge: Harvard University, 1969.

Geis, Fred Jr. *The Semantic Differential Technique as a Means of Evaluating Changes in 'Affect'.* Unpublished doctor's thesis. Cambridge: Harvard University, 1969.

Lapp, Douglas M. *Physics and the Disadvantaged Learner: Case Studies of Two Students in an Inner-City School.* Unpublished doctor's thesis. Cambridge: Harvard University, 1967.

Poorman, L. Eugene. *A Comparative Study of the Effectiveness of a Multi-Media Systems Approach to Harvard Project Physics with Traditional Approaches to Harvard Project Physics.* Unpublished doctor's thesis. Bloomington: Indiana University, 1967.

THE PROJECT PHYSICS LEARNING MATERIALS

The Project Physics Course includes texts, student handbooks of laboratory and other activities, laboratory equipment, programmed instruction, tests, film loops (and some longer films), overhead transparencies and books of selected readings. These varied learning materials make possible a more effective use of your capacities as a teacher in providing for individual differences and environmental contingencies. In a word, they permit you to shape the course to fit the diverse needs and interests of your students.

Each of the kinds of materials has been designed to perform special and sometimes multiple functions in the course. Sometimes a given learning material serves a unique purpose in the course and sometimes it overlaps with others. You should develop a clear notion of what roles these materials can play in your classes and for your students, as such an understanding is essential for their effective use.

TEXT

One of the important learning materials in the Project Physics Course is the *Text*. It is, however, *only* one component of the course and should not be thought of as anything more. It shares with the laboratory, the films, the *Handbook*, and the rest the task of helping the student learn some significant amount of physics. The Project Physics Course simply cannot properly be taught using the *Text* alone. Nor can the course be effectively taught without it.

If the *Text* has any unique function to serve, it is as a systematic guide for the student. It presents the main concepts to be dealt with in the course and establishes the logical and developmental relationships among those concepts. For this reason the *Text* is frequently referred to as "the student guide." A road map may be enormously helpful in establishing direction and perspective, but reading a map is not an adequate substitute for an actual drive through the mountains, or even for a good motion picture of such a drive. The physics *Text* alone is not able to supply the rich variety of insights and experiences needed to make the course intellectually and emotionally enriching. Thus it would be a mistake to assume that students can master topics just because they are introduced or used in the *Text*. From time to time, indeed, the *Text* treatment of a topic (for example, vectors), is deliberately shallow or incomplete just because there exist in the course other instructional materials which can deal with that topic more effectively. The overprinted student text pages in this *Teacher Resource Book*, as well as the chapter organizational charts, attempt to clarify for you the relationships between the *Text* and the other course materials.

The value of the *Text* to the students depends to a large extent on how they use it. Most important, they should look upon it as a conceptual guide that presents ideas, discusses those ideas in a broad context, and raises issues. Students should not look upon the *Text* as an infallible compendium of the facts of physics.

Great care has gone into trying to make the *Text* as cogent and understanding as possible. The level of reading difficulty was reduced as far as seemed consistent with presenting the ideas at a level suitable for high school students. Students who have trouble reading can still understand what the *Text* is saying if they will work reasonably hard at it. Similarly, students do not have to have highly developed matematical *skill* in order to follow the *Text* discussion. This is not to say that the Project Physics Course ignores mathematics. Indeed, a determined effort is made to help students come to *understand the role* of mathematics in physics even though they themselves never become competent practitioners of advanced mathematics.

You can help your students utilize the *Text* more efficiently than they might otherwise do by insisting on these techniques.

1. The Prologue and the Epilogue of each unit should be taken seriously. By reading the Prologue carefully and then referring to the table of contents from time to time, the student will find he is better able to keep his work in focus. Reading the Epilogue will reinforce the major thrust of the unit and help the student make connections with the unit which follows.

2. In studying any particular chapter, a student should first of all *rapidly* skim the entire chapter. This overview (along with occasional reference to the chapter table of contents) will help direct him as he then studies in detail the individual sections of the chapter.

3. As soon as a student finishes studying a given section, he should immediately answer the end of section questions and check his answers against those given in the back of the *Text*. These questions are intended to enable the student to find out for himself whether or not he grasped the one, two or three main ideas in that section. If he finds that his answers are correct, then his learning will have been rein-

forced and his self-confidence enhanced. If his answers are wrong, he should then restudy the section.

The *Study Guide* at the end of each chapter is also intended to help the student learn physics. How the *Study Guide* is used depends to some extent, however, on how the teacher decides to organize instruction (see the section which follows on instructional approaches to the Project Physics Course). In some situations, the teacher customarily assigns "problems" to be done at night by the students. In other situations the teacher does not assign homework, but leaves that to student judgment. In either case, it should be kept clearly in mind that each *Study Guide* contains many different kinds of items. There are short-answer questions, essay questions, drill problems and problems based upon real events, questions and problems relating physics to other sciences, derivations to be completed, and activities to be carried out. Furthermore, these items range in difficulty from very easy to extremely challenging.

Clearly then, a student should not be expected to do everything in the *Study Guide*. Either the teacher or the student himself must make a wise selection. To help students determine which *Study Guide* items are relevant to a particular part of the text, all *Study Guide* questions have been keyed to the margins of the text. Also, answers to approximately half of the *Study Guide* items are listed at the end of the *Text*.

One other feature of the Project Physics *Text* needs to be mentioned. Since many teachers do use an independent learning approach that puts much of the responsibility on the student, it was felt necessary to make the *Text* as much like a guide as possible. It is for this reason that all of the learning materials associated with a given unit of the *Text* (film loops, experiments, activities, films, programmed instruction booklets, readers, transparencies, supplementary units and tests) are listed at the beginning of the *Study Guide* for each chapter. Many of these are also indicated at appropriate places in the margin.

The *Teacher Resource Book* for each unit discusses the background and development of ideas of the whole *Text* and of each chapter. It should be pointed out that although the Project Physics *Text* is published in two forms, hard cover and soft cover, the content and page by page design are identical. In the hard cover form the six text units are bound together into a single book and the corresponding six student *Handbooks* are available in separate, single soft-cover books. In the soft-cover form each separate text unit is bound together with its corresponding *Handbook*. The *Teacher Resource Book* serves the hard and soft bound forms equally well.

HANDBOOK AND LABORATORY

The students' experiences with nature in the Project Physics Course are provided primarily through student experiments, teacher-group experiments and teacher demonstrations—and only secondarily by means of film loops, sound films, transparencies and programmed instruction materials. In addition, many opportunities for interested students to carry out investigations or activities on their own in school or at home are suggested in the *Handbook*. From this collection of activities every student should find something appealing.

Teacher demonstrations present phenomena with the student cast in the role of spectator —although hopefully not as an entirely passive one!

In *teacher-group experiments* students are encouraged to make observations and collect data, participate in the analysis and interpretation of the data. This technique can furnish precise data or opportunities for you to make persuasive observations in response to student arguments or questions.

Student experiments are exercises performed by the student himself in the laboratory. Here the individual student (or a small group of students) organizes and manipulates the apparatus, carries through the required steps, answers questions as they arise, and then draws his own conclusions. Individual results vary, of course, and thus at times only the pooling of results from all of the students (or student groups) will lead to useful conclusions from which generalizations can be made. Throughout the course, the *purpose* of the experiment and *plan* of investigation should comprise the majority of your pre-lab discussions, while the *analysis* should always be a part of post-lab discussions.

A description of the experiments for each chapter and comments on them are found in the Experiment sections of each *Teacher Resource Book*. A briefer description and list of equipment needed for each experiment is included in the section dealing with Organization of Instruction. Descriptions of demonstrations are located in the Demonstration section of each *Teacher Resource Book*.

Whether the experimental work at a given point in the course takes the form of teacher demonstrations, teacher-group experiments or student experiments, you should decide ahead of time what the main purposes of the activity

are. In the Project Physics Course, any given experiment may serve one or more of the following student purposes:

1. To become familiar with some of the phenomena with which the course deals. Thus, even before they "understand" them, students should encounter cases of uniform acceleration, wave refraction, spectra and the like.

2. To provide one of several approaches to the understanding of an important physical concept. Some students seem to learn best through laboratory activity, whereas others can learn by reading, viewing films, discussion, or even listening to lectures. In this sense, laboratory, is simply one of the learning media.

3. To learn something about the nature of experimental inquiry and the role of the laboratory in the advancement of scientific knowledge.

4. To learn some things about the physical world other than by written or oral assertion; in a sense to "discover" something.

5. To have a pleasant experience. One of the advantages of science (and art and drama) courses over many others is that there are active, nonbookish ways for the student to become involved. With help and reassurance it is likely that even the most apparatus-shy youngster can learn to operate effectively in the laboratory and to enjoy doing so. It is probably important for students' long-run achievement in the course that the laboratory activity be a pleasant experience even for those who do not become terribly good at it.

The *Handbook* is a somewhat unique document. It is much more than a laboratory guide in that it also contains student activities and film loop notes. The Activity section of each chapter of *Handbook* should guide your students into interesting investigations beyond the usual classroom laboratory activities. It lists a variety of activities and materials to assist them in learning more effectively the conceptual material treated in the *Text* and can take them beyond the *Text*.

The *Handbook* should, above all, help you to tailor the Project Physics Course to the interests and strengths of individual students. This is why such a wide variety of experiments and activities, ranging from simple to complex and touching on many aspects of physics, were included in the *Handbook*.

THE READER

There are six collections of articles from periodicals and textbooks, bound in paperback Project Physics *Readers*, one for each of the six units of the text. Descriptions of *Reader* articles will be found in the section of each *Teacher Resource Book* entitled Brief Description of Learning Materials. Also, a very brief summary of the content of each *Reader* article is printed right above the title in the *Reader* itself. Biographical information about the authors is contained in the back of each *Reader*.

We suggest that the *Readers* be made available to students at all times. If some sign-out system is necessary, it should be the responsibility of the students and require a minimum amount of paperwork on your part. This does not mean, however, that the *Readers* can be put on a shelf and just left there for the students to read when they "get interested." An important element in making the *Reader* attractive to students is the manner in which you make reference to specific articles. For example, you might try, now and then, reading short quotations from articles during class time—without, however, letting this take much time from other class activities. But most of all, you should become as familiar as possible with the *Reader*, so that you can refer students to specific articles when their interest in a certain topic is revealed during class discussion.

The *Reader* is not a textbook. It is not even a supplementary textbook. You need not require that every student read a certain article. You should assign *Reader* articles only occasionally, trying to guide students to these articles in such a way that they discover by themselves how interesting many of them are.

The very nature of the *Reader*—a collection of many different types of articles by authors living at different times and working in different fields—makes some part of the *Reader* potentially appealing to every student. This potential can be distorted if the student gets the feeling that the *Reader* is just one more piece of the package which must be studied and "learned" by exam time.

Some teachers have students turn in a brief comment on all articles they read. Other teachers have students jot down their reactions or comments in their course notebooks. These and other techniques can work providing they do not become too formal and restricting. Your attitude toward the *Reader*, and the manner in which you present it to your class will determine how the *Reader* is accepted by your students.

PROGRAMMED INSTRUCTION

Each Project Physics *Programmed Instruction Booklet* presents a carefully graded sequence of tasks to the student. The sequence has been designed to assure a high degree of

success and to provide each student with information about the correctness of his response or answer. This enables the student to learn by himself and increases the probability that he will stay on the right track.

Sample questions for each *Programmed Booklet* generally appear at the beginning of each booklet. Students are instructed to try the sample questions and, if they have difficulty, to complete the booklet. Programs can be used either in class or as homework. While taking a program, and sometimes after taking it also, the student may still have questions. However, his need for help from you in solving problems at the end of the chapter or in learning certain difficult concepts from the *Text* will decrease. No less than with other learning materials, you are urged to go through the programs yourself if you intend to use them; this will alert you to student questions which are likely to arise.

It is important that students refrain from spending too much time on programmed instruction at first, since the degree of concentration required may result in a negative reaction if the student has not become accustomed to it. Sessions of fifteen minutes or less are best at first. This is one of the reasons why the Project Physics programs are brief. Another reason is that each program deals only with a restricted set of concepts or skills. Still another reason for short programs is that any given program is not meant to stand alone, but is rather one of an array of learning materials dealing with a topic.

FILM LOOPS (8mm)

There are forty-eight Project Physics *Film Loops*. The 8mm loops, packaged in cartridges and adaptable to any reel type super-8 projection, require 3 to 4 minutes running time.

The Project Physics *Film Loops* are closely integrated with other Project Physics Course materials, and are intended both to complement and to supplement them. Some of the *Film Loops* are purely qualitative demonstrations in physics, but the majority are quantitative. For the best results, the student should not just passively view these films, but rather he should take data from the projected images and then analyze them himself.

Instructions for the specific uses of each of the *Film Loops* are found in the *Handbook*. In addition, the contents of the loops are summarized in the section of the Teacher Guide entitled Film Loop Notes.

SOUND FILMS (16mm)

There are three Project Physics films. These are: *People and Particles*, *Synchrotron*, and *The World of Enrico Fermi*. The first of these is suitable for general viewing very early in the course, and again very late in the course. The second is, in effect, a tour of the Cambridge Electron Accelerator and can be shown during Unit 6. The last film is a two-part biographical film on Enrico Fermi, and while it can be reasonably shown either at the beginning of the course or at the end, the latter choice is probably preferable. By that time, many of the individuals seen and heard in the film (Bohr, Einstein, Planck, etc.) will have been encountered in the *Text*.

The main purpose of these films is to give an accurate portrayal of some of the social, cultural, psychological, and historical aspects of scientific work. In both *People and Particles* and *The World of Enrico Fermi*, we see real scientists at their work and hear them commenting on many of its features. Thus, these two documentary films are especially important to the broader aims of the Project Physics Course and should be shown if at all possible.

There are, of course, many excellent physics films in addition to the Project Physics films described. Many of these are keyed into the course and noted in several places in the *Teacher Resource Book*. You should, however, use (and add to the list) other films that you find relevant and effective.

TRANSPARENCIES

For each of the six units of the Project Physics Course there are about eight color transparency sets. Each of these sets deals with a specific topic and is itself made up of from three to six overlays. The transparencies can be marked on with wax pencils and water soluble ink.

The transparencies for any one unit are collected together in a *Visu-book*. This allows the transparencies to be used with convenience and flexibility on any projector 10″ X 10″ or larger. The individual overlays can be shown in the order in which they are placed in the *Visu-book* or in another desired order.

More than other materials in the Project Physics Course, the transparencies are teacher-oriented. While some teachers find that it is useful to allow small groups of students to use the transparencies for study purposes, most teachers utilize them in making their own presentations. In either case, the transparencies are useful because they accurately portray diagrams that are difficult to put on the blackboard and because they allow one to present a complex development step by step. Some of the transparencies are most useful in presenting new ideas and skills, while others are most effective when used to help summarize a concept.

In each *Visu-book*, the sets of transparencies are separated by a heavy fiberboard sheet. On this sheet are printed suggestions for the use of the overlay. Summaries of the individual transparency sets are given in the section of each *Teacher Resource Book* entitled Brief Descriptions of Learning Materials. Indications on when to use each one are given in the various chapter resource charts of the *Teacher Resource Book* and in the overprinted text component of the *Resource Book*.

SUPPLEMENTAL UNITS

In order to accommodate the wide range of interests, talent and background among students and teachers, the Project Physics Course was intentionally designed to provide substantial diversity and flexibility. This is why the large array of multimedia multimodal learning materials described above was developed and coordinated into the basic course units. In order to insure conceptual structure and continuity, and to provide a common core of topics, all students are expected to study the six basic units, even though individual students, using the unit learning materials, may study the core topics from different perspectives, in different ways, and to different levels of sophistication. The Project Physics *Supplemental Units* provide quite another opportunity for the teacher to adjust the course in the light of his own and his students interests.

The basic Project Physics Course was deliberately designed to be less than a full year's study for most students. Thus even a class made up entirely of academically slow and poorly prepared students working under adverse conditions will complete the basic course within the school year, and while they will not have covered as many topics as are found in the *books* of other physics courses, what they do study will be significant, have structure and be complete in itself. For most classes, however, the six basic units will be completed in six to eight months, leaving ample time to augment the course with the study of one, two or three Supplemental Units. It will eventually be possible to select these units, which can be used by individual students, small groups or an entire class, from a pool of about twenty.

Some of the projected Supplemental Units are historical or methodological, some focus on the laboratory, some have an engineering bias, some deal with connections between physics and other sciences or disciplines, and some deal with in depth with a special physics topic. Units on Optics and on Electricity and Electronics are nearing completion, and two, *Elementary Particles* by Haven Whiteside and *Discoveries in Physics* by David L. Anderson, are in press. Others will be announced as they appear in the near future.

Elementary Particles focuses on acceleration and bubble chamber experiments which have revealed photographic evidence of over 200 different particles believed to be the basic building blocks of nature. In this unit the students have an opportunity to make calculations and inferences based on actual measurements of tracks on bubble chamber photographs.

In *Discoveries in Physics* four separate case studies are presented. These serve as the basis for a thoughtful and informed analysis of the ways in which discoveries are made and of the various meanings for "discovery." The discoveries examined are of the planet Neptune, nuclear fission, the neutrino, and cathode rays.

TESTS AND STUDENT EVALUATION

To develop a testing program and an approach to grading that will serve sound student and teacher purposes is clearly a difficult task. The difficulty is probably compounded in the case of a course, such as Project Physics, that is new and different in its objectives, content, approach and instructional materials. Thus, there will inevitably arise questions concerning the testing and grading of students taking this course. We hope that the following comments may be of some assistance as you make your own evaluation decisions.

Evaluation of the *growth* of each student during a course is essential, and teachers do this in various ways. Students expect that the criteria used will be "fair," that is, consistent with and representative of the overall objectives of the course. For the Project Physics Course this "fairness" requires an extension of the usual bases of student evaluation and grading. The course deliberately provides many opportunities for student initiative and for individualized learning; it permits different students to pursue different interests and to shape for themselves somewhat different experiences. It follows that each student ought to have oppoturnities to demonstrate his achievement in the areas of his interests and to select the means by which he can best demonstrate this achievement. Clearly the ritual of formal testing, with its tensions, the inevitable artificial numerical problems, and pressures of time can at best only provide one of many kinds of information on which to assess student achievement. Although Project Physics had carefully produced four different tests for each Unit, *scores on these tests should not be taken as the sole basis*

on which each student's achievement is assessed and graded.

Proper recognition must be given to many student behaviors which can be observed and recorded by the teacher. Examples are: interest expressed by student questions and self-initiated work, extra reading, creation of models representing theories, observations of the way physics operates in the world, literary and other artistic elaboration or criticism of concepts, and historical studies. These accomplishments might take the form of research papers, creative writing, critical book reviews, debates and discussions, adaptations and extensions of laboratory experiments, further mathematical exploration of the laws of physics, and classroom leadership functions. Both individual and small group approaches should be acceptable.

It is in the context of these beliefs about student evaluation that the Project Physics *Tests* should be understood. For each unit of the course there is a Project Physics test booklet containing four tests. Teachers can choose from each set of tests those which seem to be most appropriate for their students. Each set of unit tests includes a 40-item multiple-choice test, a test composed of problems and essay questions, and two tests containing different mixtures of multiple choice items, essay questions and problems. Students have some choice of questions to answer on all except the 40-item multiple-choice test. Questions have been assigned to the various tests with the intention of making the several tests in each booklet nearly alike in difficulty and coverage. Suggested answers for all questions are provided for the teacher in the Answers to Tests section of *Teacher Resource Book*.

The objectively-scored items in each Project Physics unit test booklet and in the mixed tests have been selected with care to represent reasonably well the range of topics considered in the Unit. Most of the items have been used in previous years and have been examined through item analysis for difficulty and discriminating power. Although there are some obviously hard items, most of the items in these objectively-scored tests have about the same level of difficulty for students enrolled in Project Physics classes.

The multiple-choice tests have been developed with the expectation that average scores would be between 65 and 70 percent. Such scores are reasonably encouraging to students, yet allow room at the top for the demonstration of higher achievement, as well as room at the bottom. On such tests 20 to 25 percentage points would be expected from random guessing among the alternative responses.

The particular pattern of tests selected by Project Physics has resulted from extensive discussions about the effectiveness of various means of estimating student learning. The multiple-choice form of tests is widely used because it can be scored quickly and has predetermined answers. However, as various critics have pointed out, most objectively scored tests require only the selection of the best choice from among a limited number of alternatives. Such items do not oblige the student to appraise the relevance of what he knows, and then express it coherently and concisely in his own words. The critics of "objective testing" maintain that the student learns that broader comprehension and ingenuity are not rewarded on tests.

Recognizing the limitations of objectively-scored tests, the Project Physics test booklets also include essays and problems. Essay items require the student to analyze the question, decide what he knows that is relevant, and then frame a coherent but brief answer. The Group I questions should each take about five minutes to answer adequately, while the Group II questions should take about ten minutes. *Caution:* Because science students in some schools have not taken essay tests for some years, if ever, the teacher may need to discuss with the students what constitutes an adequate answer, and then provide practice on one or two sample essay items well in advance of giving such a test.

The mixed tests, which include both multiple-choice items, essay questions and problems, may be a more realistic means of probing the range of student learnings than either a test made up entirely of multiple-choice questions or of essay questions and problems. In any case, the four tests in each booklet exist as a resource, and it is up to the individual teacher to decide how best to use them.

However the unit tests are administered, the problem of grading will still remain. Each teacher will assign the grades he feels are appropriate in terms of the total information available about the achievement of each student and not on the basis of test scores alone. The criteria for grades should be broad, and students enrolled in Project Physics should, on the average, receive grades no lower than those they receive in their other courses.

Application of this premise is of central importance if more students are to elect to study physics. If teachers persist with the assumption that acceptable achievement in the study of physics can only be demonstrated through skill in the solution of complex mathematical problems, or if teachers make grading standards so rigid that students are reluctant to risk taking

the course, then Project Physics will not appeal to many students and enrollments in physics cannot be expected to rise.

While there is no single or "best" basis for weighing the various evidence of student achievement, the blending of test results with other data is surely necessary. Unusual achievement on any aspect of the course, such as student activities, should compensate for somewhat lower achievement on other aspects. Such a procedure would, for example, balance high abstract mathematical but low humanistic social achievement for one student with the converse pattern for another student. Only a broad assessment of student achievements across the wide range of opportunities provided in this course will make clear to successive classes of Project Physics students that teachers really believe all students can profit, in different ways, from a study of physics.

INSTRUCTIONAL APPROACHES TO THE PROJECT PHYSICS COURSE

The Project Physics Course was deliberately conceived to promote flexibility of instruction. Given the great diversity of students, of teaching situations, and of teachers, there is no one absolutely best way to teach physics or any other subject. It seemed that what was needed was the kind of supple course that could be adapted to the realities of the educational variables.

Thus Project Physics is not a monolithic course that must be taught one way and one way only. Indeed, there are many effective approaches and you are urged to experiment in order to determine the ways which suit you, your students, and your situation best. Please do experiment critically and with an open mind! As you introduce the Project Physics Course do not immediately assume that the way you have always taught physics is the only way for you to teach in all situations. Try the ways suggested here and also other methods that you may know about. With experience you can become competent in a variety of approaches to classroom instruction.

Three general kinds of approaches to the teaching of Project Physics are outlined here. The names assigned to those approaches should not be taken too seriously, nor is it necessary to look upon these as mutually exclusive categories.

CONVENTIONAL TEACHING METHODS

The so-called conventional or traditional ways to teach a science course involve some mixture of lecture, lecture-discussion, teacher demonstrations, and laboratory sessions in which students working in groups perform the same experiment, homework assignments, and testing, all under the direction of the teacher.

Perhaps the main advantage of this approach is that it is the one with which teachers are most familiar. This is what they themselves experienced in nearly all of their science courses from high school through college. The techniques are well known. There are some dangers and disadvantages, however. For one thing, the focus is on the imparting of information. More than any other approach this requires that the teacher be firmly grounded in classical and modern physics, in related sciences, and in the history and philosophy of science, and that he keep up to date. It has the added disadvantage that it is not easily adapted to the ability and interests of the individual students.

In any event, the learning materials of the Project Physics Course are easily adaptable to this method. The *Teacher Resource Book* provides background information on the topics being covered in the course, suggests a variety of demonstrations, and keys in the various teaching aids, such as the transparencies for the overhead projector, film loops, etc.

To teachers who do wish to follow the conventional approach we make the following suggestions:

1. Attempt to reduce lectures in favor of class discussion and laboratory activities. The *Text* is deliberately written in such a way that most students can get the information they need directly from the *Text* and monitor their own learning as they proceed. Thus the teacher can use his lecture time for developing important ideas that are of special interest to his students or which may be particularly difficult for many students.
2. During the laboratory period consider allowing different students to work on different experiments from time to time. The *Handbook* provides an ample selection of experiments to introduce such variety into the laboratory.
3. Utilize the Project Physics *Readers* and *Programmed Instruction Booklets* to introduce some individualization into the course.

THE MULTI-MEDIA SYSTEMS APPROACH

This approach has been devised to exploit the rich multi-media learning resources of the course. For each unit a day-by-day schedule has been worked out that represents one of many ways of incorporating available materials and media and that suggests different approaches to teaching and learning which these media make possible. The system is designed so that the bulk of the information dissemination aspects of teaching are based upon the interaction between students and the learning materials, thus freeing the teacher to assume the roles of monitor, guide, and consultant.

One objective of the multi-media systems approach is to encourage and make possible individualized instruction and a variety of experiences in the classroom. It also emphasizes the need to introduce physical phenomena before generalizing and abstracting physical laws from them. The system makes use of such techniques as "laboratory stations" for qualitative experience with phenomena, "small group discussions" to encourage a high level of individual participation, and various classroom activities designed to reinforce attention to historical, philosophical, and sociological aspects of physics.

As with any other approach to the teaching of the Project Physics Course the teacher

should keep notes as he teaches one or more units the first year. On the basis of his experience he can then modify the multi-media sequence during the second and subsequent years until he is satisfied with it. Even then, of course, he should continue to alter the program as new instructional materials become available in the future.

INDEPENDENT LEARNING APPROACHES

Both of the previously described instructional approaches are teacher-dominated in the sense that the teacher determines the goals of instruction, the sequence of classroom experiences, and the work to be done by the students out of class. The various independent learning approaches that have been tried differ from the above pattern in that the teacher transfers some of these responsibilities to his students.

The basic idea is that within the framework of a given course unit each individual student decides for himself which aspects of the topics he wishes to concentrate on, which instructional media he will use to learn from and what work he will do out of class. Under this plan the students are told, when beginning a new unit, which general ideas they will be held responsible for, what learning materials are available, and how much time will be spent on the unit. It is then up to a student to decide whether he wishes to concentrate on an overall view, on an historical approach, on the experimental or mathematical aspects, or on some other approach. In order to do this he is permitted to use whatever film loops, experimental apparatus, readings or other materials are available.

The teacher's job is to motivate individual students, to help them get started, to give them suggestions on how to study or which materials to use. He will also work with individual students and small groups as they need help in solving problems, in understanding the *Text*, in carrying out experiments, or whatever. Note that the teacher, in this approach, is very deeply engaged in guiding each student as needed. The students are not simply "turned loose" to struggle through the course entirely on their own.

There are, to be sure, many variations on this approach. Some teachers, for example, divide the class into groups and require that each group of four students turn in a minimum amount of work, usually specified. Other teachers utilize a "contract system" whereby individual students and the teacher agree ahead of time on the amount and quality of the work to be carried out by the students in return for a specified grade. Some examples of such contracts are included in the *Teacher Resource Book*. Still other teachers provide students with a list of chapter learning objectives and a listing of required and optional activities that lead to the attainment of those objectives. Examples are given for each unit.

What all of these variations have in common is that they place the major responsibility for learning on the shoulders of the student himself. The main rationale for this is that to succeed in the modern world each person must eventually become an independent learner. He must learn how to decide for himself what it is he needs to know and how to go about learning it. If we want students to be able to organize and monitor their own learning then we must give them the chance to develop this skill.

The evidence in trials so far indicates that the risks inherent in independent learning approaches are not as great as many teachers might expect. While students frequently do not like this approach at first, because they find themselves initially confronted with unusual responsibilities, they nevertheless do quite well. Performance is at least as good on physics achievement tests as under more conventional approaches. Also, students come to appreciate having the opportunity to follow their own interests and to develop their skill as independent learners.

Teachers who use this approach do not spend much time preparing lectures or correcting homework papers. However, they usually report that this is a very taxing method of instruction. Every class session is an intensive, concentrated period of teaching in the fullest sense. As soon as the individual rather than the class becomes the focus of instruction it turns out that some students require a great deal of attention and some very little; some merely need to be guided and motivated whereas others have to be helped every step of the way. The teacher must at times give nearly full attention to one or two students who are poor readers, mathematically unskilled or maladroit with apparatus while at the same time keeping his eye on other parts of the room where experiments and other activities are going on.

Individualizing instruction is possible provided that there is a rich enough variety of learning materials bearing on a given subject (as there is in the Project Physics Course) and that the teacher is willing to try novel methods of instruction (as many are). The purpose of this approach is not to bring the "class" to some level of understanding of physics but rather to help as many individuals as possible attain as much as they can in physics and particularly in those aspects of physics that interest them most.

CONTENT IN BRIEF

Unit 1 Concepts of Motion

How do things move? Why do things move? The principal task of Unit 1 is to lead students to answers to these questions. A secondary task is to provide insight into the way scientists go about their work.

The basic question of kinematics (how do things move?) is introduced first. This question is answered gradually, starting with a very simple motion and proceeding to more complex motions.

Chapter 1: The Language of Motion
The motion of things. A motion experiment that does not quite work. A better motion experiment. Leslie's "50" and the meaning of average speed. Graphing motion and finding the slope. Time out for a warning. Instantaneous speed. Acceleration—by comparison.

Chapter 2: Free Fall—Galileo Describes Motion
The Aristotelian theory of motion. Galileo and his time. Galileo's *Two New Sciences*. Why study the motion of freely falling bodies? Galileo chooses a definition of uniform acceleration. Galileo cannot test his hypothesis directly. Looking for logical consequences of Galileo's hypothesis. Galileo turns to an indirect test. Doubts about Galileo's procedure? Consequences of Galileo's work on motion.

Chapter 3: The Birth of Dynamics—Newton Explains Motion
Explanation and the laws of motion. The Aristotelian explanation of motion. Forces in equilibrium. About vectors. Newton's first law of motion. The significance of the first law. Newton's second law of motion. Mass, weight, and free fall. Newton's third law of motion. Using Newton's laws of motion. Nature's basic forces.

Chapter 4: Understanding Motion
A trip to the moon. Projectile motion. What is the path of a projectile? Moving frames of reference. Circular motion. Centripetal acceleration and centripetal force. The motion of earth satellites. What about other motions?

EXPERIMENTS AND ACTIVITIES

Experiments
Naked Eye Astronomy
Regularity and Time
Variations in Data
Measuring Uniform Motion
A Seventeenth-Century Experiment
Twentieth-Century Version of Galileo's Experiment
Measuring the Acceleration of Gravity
(A) a_g by direct fall
(B) a_g from a pendulum
(C) a_g with slow motion photography (film loop)
(D) a_g from falling water drops
(E) a_g with falling ball and turntable
(F) a_g with strobe photography
Newton's Second Law
Mass and Weight
Curves of Trajectories
Prediction of Trajectories
Centripetal Force
Centripetal Force on a Turntable

Activities
Using the Electronic Stroboscope
Making Frictionless Pucks
When is Air Resistance Important?
Measuring Your Reaction Time
Experiencing Newton's Second Law
Making Accelerometers
Speed of a Stream of Water
Photographing a Waterdrop Parabola
Motion in a Rotating Reference Frame
Measuring Unknown Frequencies

LEARNING MATERIALS

Programmed Instruction Booklets

Vectors 1 The Concept of Vectors
Vectors 2 Adding Vectors
Vectors 3 Components of Vectors
Equations 1 Solving Simple Equations
Equations 2 Application of Simple Equations
Equations 3 Combining Two Relationships

Film Loops

Acceleration Due to Gravity—Method I
Acceleration Due to Gravity—Method II
Vector Addition—Velocity of a Boat
A Matter of Relative Motion
Galilean Relativity I—Ball Dropped from Mast of Ship
Galilean Relativity II—Object Dropped from Aircraft
Galilean Relativity III—Projectile Fired Vertically
Analysis of a Hurdle Race—Part I
Analysis of a Hurdle Race—Part II

Sound Films (16mm)

People and Particles
The World of Enrico Fermi

Reader Articles

The Value of Science
by Richard P. Feynman
Close Reasoning
by Fred Hoyle
On Scientific Method
by P. W. Bridgman
How to Solve It
by G. Polya
Four Pieces of Advice to Young People
by Warren W. Weaver
On Being the Right Size
by J. B. S. Haldane
Motion in Words
by J. B. Gerhart and R. H. Nussbaum
The Representation of Movement
by Gyorgy Kepes
Motion
by R. P. Feynman, R. B. Leighton, and M. Sands
Introducing Vectors
by Banesh Hoffmann
Galileo's Discussion of Projectile Motion
by G. Holton and D. H. D. Roller
Newton's Laws of Dynamics
by R. P. Feynman, R. B. Leighton and M. Sands
The Dynamics of a Golf Club
by C. L. Strong
Bad Physics in Athletics
by P. Kirkpatrick
The Scientific Revolution
by Herbert Butterfield
How the Scientific Revolution of the Seventeenth Century Affected Other Branches of Thought
by Basil Willey
Report on Tait's Lecture on Force:—B. A. 1876
by James Clerk Maxwell
Fun in Space
by Lee A. DuBridge
The Vision of Our Age
by J. Bronowski
Becoming a Physicist
by Anne Roe
Chart of the Future
by Arthur C. Clarke

Transparencies

Using Stroboscopic Photographs
Stroboscopic Measurements
Graphs of Various Motions
Instantaneous Speed
Instantaneous Rate of Change
Derivation of $d = v_i t + \frac{1}{2} at^2$
Tractor-Log Problem
Projectile Motion
Path of a Projectile
Centripetal Acceleration—Graphical Treatment

CONTENT IN BRIEF

Unit 2 Motion in the Heavens

Unit 2 is an account of the physics that developed as men attempted to deal with the motions of heavenly bodies. It is not a short course in astronomy.

The climax of the Unit is the work of Newton. For the first time in history, scientific generalizations to explain earthly events were found to apply to events in the heavens as well. This remarkable synthesis, summarized in Chapter 8, had profound consequences not only in physics but also in philosophy, poetry, economics, religion, and even politics. The early chapters are necessary to establish the nature and magnitude of the problem that Newton solved. They also show that observational data are necessary to the growth of a theory. Thus Chapters 5, 6, and 7 are a prelude to Chapter 8 and constitute a case history in the development of science.

Chapter 5: Where Is The Earth? The Greeks' Answers

Motions of the sun and stars. Motions of the moon. The wandering stars. Plato's problem. The Greek idea of explanation. The first earth-centered solution. A sun-centered solution. The geocentric system of Ptolemy. Successes and limitations of the Ptolemaic model.

Chapter 6: Does the Earth Move?—The Work of Copernicus and Tycho

The Copernican system. New conclusions. Arguments for the Copernican system. Arguments against the Copernican system. Historical consequences. Tycho Brahe. Tycho's observations. Tycho's compromise system.

Chapter 7: A New Universe Appears—The Work of Kepler and Galileo

The abandonment of uniform circular motion. Kepler's Law of Areas. Kepler's Law of Elliptical Orbits. Kepler's Law of Periods. The new concept of physical law. Galileo and Kepler. The telescopic evidence. Galileo focuses the controversy. Science and freedom.

Chapter 8: The Unity of Earth and Sky—The Work of Newton

Newton and seventeenth-century science. Newton's *Principia*. The inverse-square law of planetary force. Law of Universal Gravitation. Newton and hypotheses. The magnitude of planetary force. Planetary motion and the gravitational constant. The value of G and the actual masses of the planets. Further successes. Some effects and limitations of Newton's work.

EXPERIMENTS AND ACTIVITIES

Experiments

Naked Eye Astronomy
Size of the Earth
The Height of Piton, a Mountain on the Moon
The Shape of the Earth's Orbit
Using Lenses to Make a Telescope
Orbit of Mars
Orbit of Mercury
Stepwise Approximation to an Orbit

Activities

Making Angular Measurements
Celestial Sphere Model
Scale Model of the Solar System
Stonehenge
Moon Crater Names
Frames of Reference
Three-Dimensional Model of Two Orbits
Inclination of Mars' Orbit
Model of the Orbit of Halley's Comet
Haiku
How to Find the Mass of a Double Star

LEARNING MATERIALS

Film Loops and Film Strips

- Retrograde Motion of Mars (film strip)
- Retrograde Motion—Geocentric Model
- Retrograde Motion of Mars and Mercury, shown by animation
- Retrograde Motion—Heliocentric Model
- Jupiter Satellite Orbit
- Program Orbit I
- Program Orbit II
- Central Forces—Iterated Blows (computer program)
- Kepler's Laws (computer program)
- Unusual Orbits

Reader Articles

Opening Scenes
  by Fred Hoyle
Roll Call
  by Isaac Asimov
A Night at the Observatory
  by Henry S. F. Cooper, Jr.
Preface to De Revolutionibus
  by Nicolaus Copernicus
The Starry Messenger
  by Galileo Galilei
Kepler's Celestial Music
  by I. Bernard Cohen
Kepler
  by Gerald Holton
Kepler on Mars
  by Johannes Kepler
Newton and the Principia
  by C. C. Gillispie
The Laws of Motion, and Proposition One
  by Isaac Newton
The Garden of Epicurus
  by Anatole France
Universal Gravitation
  by Richard P. Feynman, Robert B. Leighton and Matthew Sands
An Appreciation of the Earth
  by Stephen H. Dole
Mariners 6 and 7 Television Pictures: Preliminary Analysis
  by R. B. Leighton and others
The Boy Who Redeemed His Father's Name
  by Terry Morris
The Great Comet of 1965
  by Owen Gingerich
Gravity Experiments
  by R. H. Dicke, P. G. Roll and J. Weber
Space the Unconquerable
  by Arthur C. Clarke
Is There Intelligent Life Beyond the Earth?
  by I. S. Shklovskii and Carl Sagan
The Stars Within Twenty-Two Light Years That Could Have Habitable Planets
  by Stephen Dole
Scientific Study of Unidentified Flying Objects
  from the Condon Report with an Introduction by Walter Sullivan
The Life-Story of a Galaxy
  by Margaret Burbidge
Expansion of the Universe
  by Hermann Bondi
Negative Mass
  by Banesh Hoffmann
Four Poetic Fragments about Astronomy
  by William Shakespeare, Samuel Butler, John Ciardi and Francis Jammes
The Dyson Sphere
  by I. S. Shklovskii and Carl Sagan

Transparencies

- Stellar Motion
- The Celestial Sphere
- Retrograde Motion
- Eccentrics and Equants
- Orbit Parameters
- Motion under Central Forces

CONTENT IN BRIEF

Unit 3 The Triumph of Mechanics

Units 1 and 2 developed the basic principles of Newtonian physics and their successful application to the astronomy of the solar system. Historically, this success led physicists in the eighteenth and nineteenth centuries to use these same principles in explaining many other natural phenomena.

Unit 3 focuses on the generalization of Newtonian mechanics by means of conservation laws for mass, momentum, and energy, and on the application of Newtonian mechanics to collisions of objects, heat, and waves.

In presenting the conservation laws, the stress is not only on physical applications but also on the historical origin of these laws in seventeenth century: the idea that the world is like a machine, which God has created with a fixed amount of matter and motion. Again, in the discussion of the generalized law of conservation of energy, attention is called to connections with steam-engine technology and other factors that prepared for the simultaneous discovery of this law by several scientists in the middle of the nineteenth century. The purpose here is to make students both competent to use physical laws and also aware of the relationships between physics and other human activities.

Chapter 9: Conservation of Mass and Momentum

Conservation of mass. Collisions. Conservation of momentum. Momentum and Newton's laws of motion. Isolated systems. Elastic collisions. Leibnitz and the conservation laws.

Chapter 10: Energy

Work and kinetic energy. Potential energy. Conservation of mechanical energy. Forces that do no work. Heat energy and the steam engine. James Watt and the Industrial Revolution. The experiments of Joule. Energy in biological systems. Arriving at a general law. A precise and general statement of energy conservation. Faith in the conservation of energy.

Chapter 11: The Kinetic Theory of Gases

An overview. A model for the gaseous state. The speeds of molecules. The sizes of molecules. Predicting the behavior of gases from the kinetic theory. The Second Law of Thermodynamics and the dissipation of energy. Maxwell's demon and the statistical view of the Second Law of Thermodynamics. Time's arrow and the recurrence paradox.

Chapter 12: Waves

Properties of waves. Wave propagation. Periodic waves. When waves meet. A two-source interference pattern. Standing waves. Wave fronts and diffraction. Reflection. Refraction. Sound waves.

EXPERIMENTS AND ACTIVITIES

Experiments

Collisions in One Dimension
Collisions in Two Dimensions
Conservation of Energy
Measuring the Speed of a Bullet
Temperature and Thermometers
Calorimetry
Monte Carlo Experiment on Molecular Collisions
Behavior of Gases
Introduction to Waves
Sound

Activities

Unusual Case of Elastic Impact
Stroboscopic Photographs of Collisions
Student Horsepower
Steam-powered Boat
Problems of Scientific and Technological Growth
Predicting the Range of an Arrow
Ice Calorimetry
A Diver in a Bottle
Rockets
How to Weigh a Car with a Tire Pressure Gauge
Perpetual Motion Machines?
Standing Waves on a Drum and Violin
Moire Patterns
Music and Speech Activities
Measurement of the Speed of Sound

LEARNING MATERIALS

Film Loops

One-Dimensional Collisions I
One-Dimensional Collisions II
Inelastic One-Dimensional Collision
Two-Dimensional Collisions I
Two-Dimensional Collisions II
Inelastic Two-Dimensional Collisions
Scattering of a Cluster of Objects
Explosion of a Cluster of Objects
Finding the Speed of a Rifle Bullet I
Finding the Speed of a Rifle Bullet II
Recoil
Colliding Freight Cars
Dynamics of a Billiard Ball
A Method of Measuring Energy—Nails Driven into Wood
Gravitational Potential Energy
Kinetic Energy
Conservation of Energy—Pole Vault
Conservation of Energy—Aircraft Take-off
Reversibility of Time
Superposition
Standing Waves on a String
Standing Waves in a Gas
Vibrations of a Rubber Hose
Vibrations of a Wire
Vibrations of a Drum
Vibrations of a Metal Plate

Reader Articles

Silence, Please
by Arthur C. Clarke
The Steam Engine Comes of Age
by R. J. Forbes and E. J. Dijksterhuis
The Great Conservation Principles
by Richard P. Feynman
The Barometer Story
by Alexander Calandra
The Great Molecular Theory of Gases
by Eric M. Rogers
Entropy and the Second Law of Thermodynamics
by Kenneth W. Ford
The Law of Disorder
by George Gamow
The Law
by Robert M. Coates
The Arrow of Time
by Jacob Bronowski
James Clerk Maxwell
by James R. Newman
Frontiers of Physics Today: Acoustics
by Leo L. Beranek
Randomness and the Twentieth Century
by Alfred M. Bork
Waves
by Richard Stevenson and R. B. Moore
What is a Wave?
by Albert Einstein and Leopold Infeld
Musical Instruments and Scales
by Harvey E. White
Founding a Family of Fiddles
by Carleen M. Hutchins
The Seven Images of Science
by Gerald Holton
Scientific Cranks
by Martin Gardner
Physics and the Vertical Jump
by Elmer L. Offenbacher

Transparencies

One-Dimensional Collisions
Equal Mass Two-Dimensional Collisions
Unequal Mass Two-Dimensional Collisions
Inelastic Two-Dimensional Collisions
Slow Collisions
The Watt Engine
Superposition
Square Wave Analysis
Standing Waves
Two-Slit Interference
Interference Pattern Analysis

Programmed Instruction

The Kinetic-Molecular Theory of Gases
Waves 1
Waves 2

CONTENT IN BRIEF

Unit 4 Light and Electromagnetism

Chapter 12 (in Unit 3) and Chapters 13 through 16 in this Unit should be considered together as an integrated sequence covering selected aspects of light, waves, electricity, and magnetism. A primary goal of the sequence is to help students reach an understanding of electromagnetic waves.

Chapter 13: Light
Propagation of light. Reflection and Refraction. Interference and Diffraction. Color. Why is the sky blue? Polarization. The Ether.

Chapter 14: Electric and Magnetic Fields
The curious properties of lodestone and amber: Gilbert's De Magnete. Electric charges and electric forces. Forces and fields. The smallest charge. Early research on electric charges. Electric currents. Electric potential difference. Electric potential difference and current. Electric potential difference and power. Currents act on magnets. Currents act on currents. Magnetic fields and moving charges.

Chapter 15: Faraday and the Electric Age
The problem: getting energy from one place to another. Faraday's early work on electricity and lines of force. The discovery of electromagnetic induction. Generating electricity by the use of magnetic fields: the dynamo. The electric motor. The electric light bulb. AC versus DC, and the Niagara Falls power plant. Electricity and society.

Chapter 16: Electromagnetic Radiation
Maxwell's formulation of the principles of electromagnetism. The propagation of electromagnetic waves. Hertz's experiment. The electromagnetic spectrum. What about the ether now?

EXPERIMENTS AND ACTIVITIES

Experiments
Refraction of a Light Beam
Young's Experiment—The Wavelength of Light
Electric Forces I
Electric Forces II—Coulomb's Law
Forces on Currents
Currents, Magnets and Forces
Electron Beam Tube
Waves and Communication

Activities
Thin Film Interference
Handkerchief Diffraction Grating
Photographing Diffraction Patterns
Poisson's Spot
Photographic Activities
Color
Polarized Light
Making an Ice Lens
Detecting Electric Fields
Measuring Magnetic Field Intensity
An 11¢ Battery
Transistor Amplifier
Inside a Radio Tube
An Isolated North Pole?
Faraday Disk Dynamo
Generator Jump Rope
Simple Meters and Motors
Physics Collage
Bicycle Generator
Lapis Polaris, Magnes
Microwave Transmission Systems
Bell Telephone Science Kits

LEARNING MATERIALS

Film Loops
Standing Electromagnetic Waves

Reader Articles
Letter from Thomas Jefferson, June 1799
by Thomas Jefferson
On the Method of Theoretical Physics
by Albert Einstein
Systems, Feedback, Cybernetics
by V. Lawrence Parsegian and others
Velocity of Light
by A. A. Michelson
Popular Applications of Polarized Light
by William A. Shurcliff and Stanley S. Ballard
Eye and Camera
by George Wald
The Laser—What It Is and Does
by J. M. Carroll
A Simple Electric Circuit: Ohm's Law
by Albert V. Baez
The Electronic Revolution
by Arthur O. Clarke
The Invention of the Electric Light
by Matthew Josephson
High Fidelity
by Edgar Villchur
The Future of Direct Current Power Transmission
by N. L. Allen
James Clerk Maxwell, Part II
by James R. Newman
On the Induction of Electric Currents
by James Clerk Maxwell
The Relationship of Electricity and Magnetism
by D. K. C. MacDonald
The Electromagnetic Field
by Albert Einstein and Leopold Infeld
Radiation Belts Around the Earth
by James Van Allen
A Mirror for the Brain
by W. Grey Walter
Scientific Imagination
by Richard P. Feynman, Robert B. Leighton and Matthew Sands
Lenses and Optical Instruments
by Physical Science Study Committee
Baffled!
by Keith Waterhouse

Transparencies
The Speed of Light
$\vec{E}$ Field Inside Conducting Spheres
Magnetic Fields and Moving Charges
Forces Between Current Carriers
The Electromagnetic Spectrum

CONTENT IN BRIEF

Unit 5: Models of the Atom

This Unit describes the development of atomic theory from the chemical atom of Dalton to the wave-mechanical model of quantum mechanics. It follows the chain of experiment and theory that led to the twentieth-century revolution in physics.

Chapter 17: The Chemical Basis of the Atomic Theory
Dalton's atomic theory and the laws of chemical combination. The atomic masses of the elements. Other properties of the elements: combining capacity. The search for order and regularity among the elements. Mendeleev's periodic table of the elements. The modern periodic table. Electricity and matter: qualitative studies. Electricity and matter: quantitative studies.

Chapter 18: Electrons and Quanta
The idea of atomic structure. Cathode rays. The measurement of the charge of the electron: Millikan's experiment. The photoelectric effect. Einstein's theory of the photoelectric effect. X rays. Electrons. Quanta and the atom.

Chapter 19: The Rutherford-Bohr Model of the Atom
Spectra of gases. Regularities in the hydrogen spectrum. Rutherford's nuclear model of the atom. Nuclear charge and size. The Bohr theory: the postulates. The size of the hydrogen atom. Other consequences of the Bohr model. The Bohr theory: the spectral series of hydrogen. Stationary states of atoms: the Franck-Hertz experiment. The periodic table of the elements. The inadequacy of the Bohr theory and the state of atomic theory in the early 1920's.

Chapter 20: Some Ideas from Modern Physical Theories
Some results of relativity theory. Particle-like behavior of radiation. Wave-like behavior of particles. Mathematical vs visualizable atoms. The uncertainty principle. Probability interpretation.

EXPERIMENTS AND ACTIVITIES

Experiments
- Electrolysis
- The Charge-to-Mass Ratio for an Electron
- The Measurement of Elementary Charge
- The Photoelectric Effect
- Spectroscopy

Activities
- Dalton's Puzzle
- Electrolysis of Water
- Periodic Table
- Single-Electrode Plating
- Activities from *Scientific American*
- Writings By or About Einstein
- Measuring q/m for the Electron
- Cathode Rays in a Crookes Tube
- X rays from a Crookes Tube
- Lighting an Electric Lamp with a Match
- Scientists on Stamps
- Measuring Ionization, a Quantum Effect
- Modeling Atoms with Magnets
- "Black Box" Atoms
- Standing Waves on a Band-saw Blade
- Turntable Oscillator Patterns Resembling de Broglie Waves
- Standing Waves in a Wire Ring

LEARNING MATERIALS

Film Loops
Production of Sodium by Electrolysis
Thomson Model of the Atom
Rutherford Scattering

Reader Articles
Failure and Success
by Charles Percy Snow
The Clock Paradox in Relativity
by C. G. Darwin
The Island of Research
by Ernest Harburg
Ideas and Theories
by V. Guillemin
Einstein
by Leopold Infeld
Mr. Tompkins and Simultaneity
by George Gamow
Mathematics and Relativity
by Eric M. Rogers
Parable of the Surveyors
by Edwin F. Taylor and John Archibald Wheeler
Outside and Inside the Elevator
by Albert Einstein and Leopold Infeld
Einstein and Some Civilized Discontents
by Martin Klein
The Teacher and the Bohr Theory of the Atom
by Charles Percy Snow
The New Landscape of Science
by Banesh Hoffmann
The Evolution of the Physicist's Picture of Nature
by Paul A. M. Dirac
Dirac and Born
by Leopold Infeld
I am this Whole World. Erwin Schrödinger
by Jeremy Bernstein
The Fundamental Idea of Wave Mechanics
by Erwin Schrödinger
The Sentinel
by Arthur C. Clarke
The Sea-Captain's Box
by John L. Synge
Space Travel: Problems of Physics and Engineering
by the Harvard Project Physics Staff
Looking for a New Law
by Richard P. Feynman
A Portfolio of Computer-made Drawings

Transparencies
Periodic Table
Photoelectric Experiment
Photoelectric Equation
Alpha Scattering
Energy levels—Bohr Theory

CONTENT IN BRIEF

Unit 6 The Nucleus

Concurrent with attempts to design better models of the atom, discoveries were made which led to the study of the nucleus itself. This Unit investigates some of these discoveries, and examines their contributions to nuclear theory and their importance to man and society.

Chapter 21: Radioactivity
Becquerel's discovery. Other radioactive elements are discovered. The penetrating power of the radiation: α, β, and γ rays. The charge and mass of α, β, and γ rays. The identity of α rays: Rutherford's "mousetrap." Radioactive transformations. Radioactive decay series. Decay rate and half life.

Chapter 22: Isotopes
The concept of isotopes. Transformation rules. Direct evidence for isotope of lead. Positive rays. Separating isotopes. Summary of a useful notation for nuclides; nuclear reactions. The stable isotopes of the elements and their relative abundances. Atomic masses.

Chapter 23: Probing the Nucleus
The problem of the structure of the atomic nucleus. The proton-electron hypothesis of nuclear structure. The discovery of artificial transmutation. The discovery of the neutron. The proton-neutron theory of the composition of atomic nuclei. The neutrino. The need for particle accelerators. Nuclear reactions. Artificially induced radioactivity.

Chapter 24: Nuclear Energy: Nuclear Forces
Conservation of energy in nuclear reactions. The energy of nuclear binding. Nuclear binding energy and stability. The mass-energy balance in nuclear reactions. Nuclear fission: discovery. Nuclear fission. controlling chain reactions. Nuclear fission. Large scale energy release and some of its consequences. Nuclear fusion. Fusion reactions in stars. The strength of nuclear forces. The liquid-drop nuclear model. The shell model. Biological and medical applications of nuclear physics.

EXPERIMENTS AND ACTIVITIES

Experiments
Random Events
Range of a and B Particles
Half-life-I
Half-life-II
Radioactive Tracers

Activities
Magnetic Deflection of β Rays
Measuring the Energy of β Radiation
A Sweet Demonstration
Ionization by Radioactivity
Exponential Decay in Concentration
Neutron Detection Problem Analogue (Chadwick's Problem)
Two Models of a Chain Reaction
More on Nuclear Fission and Fusion
Peaceful Uses of Radioactivity
Additional Books and Activities

LEARNING MATERIALS

Film Loop
Collisions With An Unknown Object

Sound Films (16 mm)
People and Particles
Synchrotron
The World of Enrico Fermi

Reader Articles
Rutherford
by Charles P. Snow
The Nature of the Alpha Particle
by Ernest Rutherford and T. Royds
Some Personal Notes on the Search for the Neutron
by Sir James Chadwick
Antiprotons
by Owen Chamberlain, Emilio Segré, Clyde E. Wiegand and Thomas Ypsilantis
The Tracks of Nuclear Particles
by Herman Yagoda
The Spark Chamber
by Gerard K. O'Neill
The Evolution of the Cyclotron
by Ernest O. Lawrence
Particle Accelerators
by Robert K. Wilson
The Cyclotron as Seen By . . .
by David C. Judd and Ronald MacKenzie
Cern
by Jeremy Bernstein
The World of New Atoms and of Ionizing Radiations
by V. Lawrence Parsegian, Alan S. Meltzer, Abraham S. Luchins and K. Scott Kinerson
The Atomic Nucleus
by Rudolf E. Peierls
Power from the Stars
by Ralph E. Lapp
Success
by Laura Fermi
The Nuclear Energy Revolution
by Alvin M. Weinberg and Gale Young
Conservation Laws
by Kenneth W. Ford
The Fall of Parity
by Martin Gardner
Can Time Go Backward?
by Martin Gardner
A Report to the Secretary of War
by James Franck, Donald J. Hughes, J. I. Nickson, Eugene Rabinowitch, Glenn T. Seaborg, Joyce C. Stearns and Leo Szilard
The Privilege of Being a Physicist
by Victor F. Weisskopf
Calling All Stars
by Leo Szilard
Tasks for a World Without War
by Harrison Brown
One Scientist and His View of Science
by Leopold Infeld
The Development of the Space Time View of Quantum Electrodynamics
by Richard P. Feynman
The Relation of Mathematics to Physics
by Richard P. Feynman
Where Do We Go From Here?
by Arthur E. Ruark

Transparencies
Separation of α, β, γ Rays
Rutherford's a Particle "mousetrap"
Radioactive Disintegration Series
Radioactive Decay Curve
Radioactive Displacement Rules
Mass Spectrograph
Chart of the Nuclides
Nuclear Equations
Binding Energy Curves

PROJECT PHYSICS TEACHER PREPARATION

The Project Physics Course was deliberately designed to be flexible and open, with a central role for the teacher. Consequently, it is of the utmost importance that teachers who plan to introduce the course be familiar with the full array of learning materials and with the various ways in which they can be used to serve individual student interests and capabilities. In addition to special training opportunities, there are two sets of materials, *Teacher Resource Books* and *Project Physics Teacher Briefing Films*, to help teachers prepare to teach the Project Physics Course.

PROJECT PHYSICS INSTITUTES

Each year the National Science Foundation supports many institutes for high school teachers of science and mathematics. A number of these, located in all parts of the country, are specifically intended to introduce physics teachers to the content, approach and learning materials of Project Physics. Upon request, the NSF (1800 G Street, N.W., Washington, D.C. 20550) will supply directories listing the locations, dates and focus of all their Summer, In-service and Academic Year Institutes, Cooperative College-School Science Programs and other teacher training programs.

Also, many local school districts, alone or in cooperation with other school districts and nearby colleges, develop programs of in-service training to assist their teachers introduce the Project Physics Course. Information on these can be obtained from the local Holt, Rinehart and Winston representative.

TEACHER RESOURCE BOOK

For each basic unit of the course, there is an extensive *Teacher Resource Book*. Its purpose is to help the teacher adapt the course to the needs of his various students. Since there are so many different materials making up the course and so many approaches are possible, the *Teacher Resource Book* is particularly important.

The *Teacher Resource Book* for each unit of the course contains: extensive comments on the organization of instruction; background discussion on the unit as a whole and on each chapter and section in the unit; descriptions of all associated learning materials; demonstration notes; experiment notes; film loop notes; equipment notes; background articles; solutions to study guide questions; suggested answers for the unit tests; an annotated bibliography; and a text unit that has been annotated with comments and suggestions for the teacher.

The *Teacher Resource Book* is in a looseleaf format in order to increase its flexibility. Teachers are encouraged to arrange the various pages for most efficient use. They are also encouraged to use selectively the suggestions appearing in the *Teacher Resource Book*, adding to or subtracting from them as they go along. In time each teacher will, in his own way, essentially design his own unique techer resource book.

PROJECT PHYSICS TEACHER BRIEFING FILMS

Twenty-one teacher briefing films have been produced to assist teachers. They are in the form of 16mm sound films for projectors and video tapes for TV use. These films deal with the management of equipment as well as with methods and styles of teaching Project Physics. However, the briefings are not intended to take the place of teacher training institutes. The film titles are:

Electron Beam Tube
Experiments with Microwaves
Film Loop Techniques I
Film Loop Techniques II
Half-Life Experiments
Informal Class Activities
Measure of Elementary Charge
Naked-Eye Astronomy
Orbit Plotting
Photoelectric Effect
Polaroid-Land Photography, Part I
Polaroid-Land Photography, Part II
Setting up the Current Balance
Teaching about Physics and Society
Teaching Style I
Teaching Style II
Teaching Style III
Using the Oscilloscope
Waves
Waves, Modulations and Commmunications
Working with the Current Balance

WHERE TO OBTAIN PROJECT PHYSICS COURSE MATERIALS

All of the student and teacher materials for the Project Physics Course are distributed by

Holt, Rinehart and Winston, Inc.
383 Madison Avenue
New York, New York 10017

These materials include:

the *Text*, Units 1–6 bound together in a hard cover
the *Handbook*, Units 1–6 bound together,

or alternatively,
the combined *Text/Handbooks* in six separate volumes

and also
Readers
Programmed Instruction Booklets
Test Booklets
Teacher Resource Books
Supplemental Units
16mm sound films
8mm film loops
(manufactured by Ealing Corporation)
film strips
transparencies for overhead projection
teacher briefing films
laboratory apparatus
(manufactured by Damon Corporation)

Catalogs of Project Physics Course materials, information about the course, and, if desired, assistance in instituting it can be obtained by contacting the New York office of Holt, Rinehart and Winston, the nearest Regional Office of Holt (listed below), or the local Holt representative.

Atlanta Office
680 Forest Rd., N.E.
Atlanta, Georgia
404-688-1133

Chicago Office
645 N. Michigan Ave.
Chicago, Ill. 60611
312-943-7575

Dallas Office
8301 Ambassador Rd.
Dallas, Texas 75202
214-637-0453

San Francisco Office
Crocker Park, P.O. Box 34400
San Francisco, California 94134
415-467-8150